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About the Journal

Founded in 2013, the Journal of Teacher Action Research (ISSN: 2332-2233) is a peer-reviewed online journal indexed with EBSCO that seeks practical research that can be implemented in Pre-Kindergarten through Post-Secondary classrooms. The primary function of this journal is to provide classroom teachers and researchers a means for sharing classroom practices.

The journal accepts articles for peer-review that describe classroom practice which positively impacts student learning. We define teacher action research as teachers (at all levels) studying their practice and/or their students' learning in a methodical way in order to inform classroom practice. Articles submitted to the journal should demonstrate an action research focus with intent to improve the author's practice.

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LEARNING THE CARBON AND NITROGEN CYCLES IN THE CONTEXT OF SOLID WASTE MANAGEMENT: THE EDUCATE, ACT, AND LIVE SCHOOL PROJECT

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Abstract This teacher action research study compared the science content learning gain of two groups of 23 seventh grade students who learned about the carbon and nitrogen cycles through project-based learning (PBL) versus other traditional teaching strategies. The PBL contextualized the content within the environmental problem of solid waste management and the solutions of composting and vertical crop planting. In both teaching strategies, students' misconceptions were directly and repeatedly addressed. A statistically significant learning gain was observed in students exposed to both teaching strategies which highlights the importance of addressing students' misconceptions during the teaching and learning processes. However, students who learned through PBL achieved significantly higher increases in learning than their peers exposed to traditional methods as assessed by three instruments that focused on content knowledge (a multiple-choice test and rubrics to assess drawings of each cycle). This result suggests differences in the depth of learning achieved by the students exposed to each teaching strategy.

Keywords: teacher action research, carbon cycle, compost, misconceptions, nitrogen cycle, PBL, preconceptions, problem-based learning, project-based learning, science education, solid waste

Introduction

From 2011 to 2017, the Center for Science and Mathematics Education Research (CSMER) from the University of Puerto Rico, Rio Piedras Campus, implemented a comprehensive project called Maximizing Yield through Integration (MYTI). MYTI was focused on developing collaborative partnerships among researchers and educators to enable STEM education research. One of MYTI's main activities was coaching mathematics and science teachers in the development and implementation of a school environmental project (SEP). The SEP was designed to facilitate the: (a) implementation of the project-based learning (PBL) teaching strategy, (b) improvement of students' mathematics and science content learning outcomes, and (c) fulfillment of a teacher action research.

This article presents the action research study carried out by one of MYTI's teacher participants to assess her students' science content learning gain as a result of their participation in the SEP called The Educate, Act, and Live (EAL) School Project. This SEP used PBL to contextualize the teaching-learning processes of the carbon and nitrogen cycles within the pressing environmental problem of solid waste management in Puerto Rico (Puerto Rico Recycling Association, 2013), and within the viable and effective alternatives of composting and vertical crop planting. The action research examined whether participation in the EAL Project promoted student learning with understanding of the following seventh grade science content: (a) the carbon cycle refers to the movement of carbon between the organic compounds that form tissue of living organisms and the carbon dioxide (CO_2) in the air, this makes photosynthesis its main process; and (b) the nitrogen cycle involves the movement of nitrogen between organisms, soil, and the atmosphere; and relies mainly on soil bacteria.

Literature Review

It is in our nature to make sense of the world. Science as a discipline does this by systematically studying the natural world in order to increase our capacity to understand and predict how it works (Chalmers, 1990). Interestingly, science, as this systematic effort to study and make sense of the world, has produced "…a body of knowledge that is in large part abstract... that is removed from experience… that has no connection with prior conceptions…and that is alien to common-sense, and in conflict with everyday experience, expectations and concepts" (Matthews, 2002, p. 129). That is, without science we are usually very mistaken about how the natural world works. We are also blind to the flaws of our unscientific meaning-making methods and their results. Hence, it is very common for people to wrongly believe that they have achieved the goal of making sense of a phenomenon. The mistaken, incomplete or inaccurate ideas and explanations students have about the natural world because of their everyday interactions with their surroundings are called misconceptions (Kumandas, Ateskan & Lane, 2019).

Students typically hold the following misconceptions about the carbon and nitrogen cycles: (a) plant acquisition of carbon is from the soil (roots) instead of from the air (leaves) through photosynthesis; (b) decomposition by soil organisms leads to the elimination instead of cycling of organic matter; and (c) respiration and photosynthesis are two separate processes that do not occur simultaneously within plants (Asshoff, Ried & Leuzinger, 2010). Moreover, Fairbanks

(2011) summarized students' misconceptions about photosynthesis and respiration this way: (a) respiration is another word for breathing and therefore can occur outside the cell; (b) plants get their food from their surroundings instead of making it from water and air through photosynthesis; (c) plants do not respire; and (d) energy in plants is provided by photosynthesis instead of respiration. In Kumandas, Ateskan & Lane's (2018) meta-analysis of research on misconceptions in biology, respiration and photosynthesis ranked the fifth most popular topic of investigation (out of 23), with a total of nine studies done from 2000 to 2014.

O'Connell (2010) argues that the strength and prevalence of the misconception that soil is a plant's main nutrient source stems from how counterintuitive is what actually occurs. For this reason, this misconception can be traced back to the Book of Genesis and Aristotle. In 1662, J.B. van Helmont demonstrated that soil was not the main source of plant biomass and mistakenly thought it should be water (O'Connell, 2008). Later, in 1804, Nicolas Théodore de Saussure determined that the source was air (Asshoff, Ried & Leuzinger, 2010). Surprisingly, the misconception that most organic material comes from and ends-up in soil is still present, and is reinforced by many Biology and Ecology textbooks currently used in schools worldwide (O'Connell, 2010).

The enormous teaching and learning challenge of these misconceptions is further enhanced by the subject's broadness and complexity (Düsing, Asshoff & Hammann, 2019). In fact, the flow of energy and matter is one of the five topics included in the National Science Teachers' Association (NSTA) publication *Hard-to-Teach Biology Concepts: A Framework to Deepen Student Understanding* (Koba & Tweed, 2009). One of the reasons behind this difficulty is that photosynthesis occurs at different levels of biological organization and thus involves various disciplines. However, according to the NSTA, its broadness and complexity often leads to limiting its teaching to the discussion of an abstract molecular process. In addition, the flow of energy and matter is usually taught in the context of a Biology class, when students have not yet taken Chemistry and their understanding of atomic-molecular level interactions is very limited. Students' learning experience of the biochemical cycles was described by the NSTA with the statement:

> …students tend to develop shallow understandings of the processes and hold on to the preconceptions they brought with them to the class. Many of these preconceptions cross grade levels and even persist in adults who, like our [college level] students, find it hard to believe that much of the mass of plants comes from the air around them. (Koba & Tweed, 2009, p. 120)

Various ways to confront and overcome the challenges associated with the teaching and learning processes of the biogeochemical cycles have been proposed and evidenced. First and foremost, misconceptions must be directly and repeatedly addressed during the teaching-learning-assessment process for learning with understanding to occur (National Research Council, 2005). Ausubel (1978, in Fairbanks, 2011, p. 2) states candidly: "The most important single factor influencing learning is what the learner already knows. Ascertain this and teach accordingly." Secondly, the broadness and complexity of the topic can be made more manageable by providing a familiar context. Asshoff, Ried & Leuzinger (2010, p. 180) explain that: “The topic is rather abstract and memorizing key principles is difficult if the topic is not consistently linked to examples or experiments.” The NSTA also argued in this regard:

What can teachers do to make this concept more accessible? In our experience, the answer is to contextualize the process in the plant, helping students to visualize photosynthesis and providing the framework to add molecular details. (Koba & Tweed, 2009, p. 120)

This action research studied PBL’s effectiveness in addressing these misconceptions and contextualizing the subject of the carbon and nitrogen cycles within the classroom teaching-learning environment. PBL is an educational strategy that engages students, for an extended period of time, in research activities designed to help them understand and find ways to contribute to the solution of a problem that is authentic and appealing to them (Lamer, Mergendoller, & Boss, 2015). PBL is characterized by: (a) contextualizing content within real world problems to help students find relevance and interest in the content and its teaching-learning processes; (b) using curriculum standards to define learning objectives; (c) building partnerships among the participants (teachers, students, experts, community members); and (d) actively engaging students in the design (propose, defend, decide how to solve the problem), implementation (carry out experiments to collect, analyze and interpret data), and assessment and dissemination of the project (Powers & DeWaters, 2004; Velázquez & Figarella, 2012). Gallagher (in Sonmez & Lee, 2003, p. 2) summarized PBL’s primary goal as “learning for capability rather than learning to acquire knowledge”.

The prolonged, interdisciplinary, collaborative and research-based learning experiences of PBL are meant to help students: (a) assume responsibility over their learning processes; (b) acknowledge the advantages of effective interactions with others; (c) maximize the ways and contexts for learning; and (d) increase their possibility of contributing to the solution of the problem through purposeful, collaborative, and reflective content learning (Velázquez & Figarella, 2012). Sonmez & Lee (2003) concluded that the increments in learning outcomes of students exposed to PBL were due to the cognitive processes required, and therefore, stimulated and developed, when: (a) content learning is contextualized, (b) students’ prior knowledge is addressed, and (c) the complexity of how students manage information is increased.

Methodology

The research question that guided this action research was: How does the carbon and nitrogen cycle learning gain of students who participate in the EAL School Project compare to that of other students exposed to more traditional non-project-based teaching strategies? In order to answer this research question, an action research was conducted using a quasi-experimental design (Hernández, Fernández, & Baptista, 2006) to compare seventh grade students’ learning outcomes as a result of their participation in the two different teaching-learning processes of the carbon and nitrogen cycles. The first author teaches middle school science in an urban public school in Puerto Rico. The participants of this study were two groups of seventh grade students (12-13-year-old boys and girls) that took their science class with her. The selected groups consisted of high achievers (at least a 3.0 GPA in a 4.0-point grade scale). Therefore, all study participants were intentionally selected (Patton, 2014) through a non-aleatory process based on their seventh-grade science teacher and their academic achievement. However, the students' participation in this study was voluntary.

The experimental group students (n=23) participated in the EAL Project using the PBL strategy during a five-month period from December 2013 until April 2014. This experimental group included three students with learning disabilities. Students in the comparison group (n=23) received the same carbon and nitrogen cycles content through more traditional teaching strategies such as searching and reading literature reviews, socialized discussions, and lectures. In both groups the carbon and nitrogen cycles were discussed and assessed in compliance with the science content standards and expectations of the Puerto Rico Department of Education (PRDE, 2014). Also, in both teaching strategies, emphasis was placed on identifying and addressing students' misconceptions. Finally, in both groups the subject of carbon and nitrogen cycles was the main focus of the science class for around six weeks. After this period, the science class moved forward according to the curriculum established by the PRDE district. However, the experimental group allocated outside class time and one class period a week for an additional three months to attend the crops being grown for the PBL (i.e., take care, and collect and analyze data). Therefore, the main difference between the two different teaching strategies was the context, relevance, and extended time provided by the PBL when framing the subject within the solid waste management problem and its possible solutions.

Three instruments were developed to measure students' conceptual knowledge of the carbon and nitrogen cycles before and after participating in the educational processes. First, an eleven-item multiple choice pre-post content test (Appendix A). This test included four items about composting, one about the Earth's naturally occurring chemical substances, four about the carbon cycle, and two about the nitrogen cycle. The four items about composting were not included in the analysis of this test's results. Important differences were expected in the students' learning on composting since the experimental group had hands-on experience with making and managing composts while the comparison group did not. Hence, in the results, this pre-post content test is presented as a seven-item test. The other two instruments were rubrics (Appendixes B and C) to assess students' pre-post drawings of each cycle. The rubrics are based on a four-point scale. The points are granted according to the degree in which specific aspects (six for the carbon and five for the nitrogen cycle) of the cycles are explained and illustrated.

Educational Intervention: The EAL Project. This section describes the EAL Project carried out with the experimental group students. Details on how to develop its activities are available in Spanish (Auccahuallpa, Feliciano-Torres, & Villanueva-Cubero, 2013).

Activity to identify the problem. Students were introduced to the subject of solid waste management in Puerto Rico's San Juan metropolitan area by viewing the eight-minute YouTube video *Trash: Problem or Treasure* (Laboy, 2011). This video focuses on the following aspects of the problem: (a) the need to close most of the landfills in Puerto Rico, (b) the average daily generation of five pounds of solid waste per person, (c) the environmental problems associated with the ineffective management of landfills, and (d) the lack of an Island wide recycling industry. A subsequent guided discussion of the video allowed the students to identify the problem, search for more information and brainstorm possible solutions. At this point, students' suggestions included the three R's of waste management (reduce, reuse, and recycle), energy recovery, and sanitary landfills. The teacher used socialized discussion to clarify the scientific concepts the students showed difficulty understanding such as: transfer of matter, energy flow, respiration, photosynthesis and decomposition.

Activity to contextualize the problem. In order to develop further understanding of the problem, its relevance, and to promote students' active engagement in finding a solution, students were invited to carry out a simple at-home garbage inventory. For one week, they classified the garbage generated in their homes according to several types of common household solid wastes. At the end of the week, the students analyzed and reflected about the types and amounts of solid waste generated by their families. The goal of this activity was to create awareness about the students' and their families' solid waste generation and management patterns. Consequently, the activity promoted students' awareness of: (a) their personal contribution to the problem, (b) different alternatives they could use in their homes to minimize the problem, and (c) the need and their duty to take action.

Activity to determine a workable solution. The different alternatives to the solid waste problem proposed during the first two activities were further researched and discussed by dividing the experimental group in five collaborative teams. Each team prepared and presented an oral report of their assigned solid waste generation and management alternative. The whole group discussions generated through the oral reports were guided by the teacher to facilitate a thorough evaluation of the presented alternatives. In this way, the students were led to choose among the five alternatives the one they would continue developing as their whole group project. As a result of these processes the students decided to focus their PBL on a combination of composting and vertical crop planting. These alternatives tackle the solid waste management problem through: (a) natural recycling of organic waste, (b) production of natural fertilizers for the crops, (c) re-use of plastic containers to plant the crops, (d) energy recovery of organic waste in the crops produced and eventually consumed by people, and (e) reduction of the solid waste (organic and plastic) that ends up in the landfills.

Carbon and nitrogen cycles' concept learning activities. The discussion of the carbon and nitrogen cycle concepts was guided by the PRDE science standards and expectations, and contextualized within the proposed solutions of composting and vertical crop planting (Figure 1). Therefore, the discussion of the cycles was focused on deciding how to maximize the viability and effectiveness of the following processes: (a) building the compost bin, (b) selecting the organic matter for composting, (c) maximizing the compost formation (observing, measuring and modifying the physical and chemical changes associated with compost formation), (d) selecting the crops, (e) selecting the type of containers for the vertical crop system, and (f) maximizing crop growth and quality.

Figure 1. A seventh-grade student checking the compost used in the vertical crop planting system (left) and an example of the final product of the vertical crop planting system using compost as a natural fertilizer (right).

Final assessment activity. The students made oral presentations of the EAL Project to the school community. They were able to show: (a) composting as a viable way to reduce the amount of organic solid waste that ends up in the landfills, (b) the vertical crop planting system as an alternative for plastic container reuse, (c) the agricultural produce grown, and (d) and explain how their participation contributed to their learning processes and academic achievement.

Results and Discussion

As previously stated, students' content knowledge learning gain of the carbon and nitrogen cycles was measured with three instruments: a seven-item content test and two rubrics to assess a drawing of each cycle. Figure 2 (below) shows the experimental and comparison groups' score distributions on the pre and post content test. Findings evidence increases in the content knowledge of both groups of students after participating in their corresponding educational interventions, both of which emphasized identifying and addressing students' misconceptions. Students' initial knowledge was minimal, as assessed by the pre content test. Score distributions indicate that the great majority (80%) of the students answered less than 50% of the pre content test items correctly. Meanwhile, posttest results show that after the educational interventions the majority (61%) of the students were able to master (≥85% score) the content knowledge assessed.

Paired sample t test results show that the experimental group participants were able to score higher in their posttest (M = 82.6%, SD = 11.6) as opposed to their pretest (M = 30.0%, SD = 14.9), a statistically significant mean increase of 52.6%, 95% CI [44.3, 60.9], $t(22) = 13.146$, $p < .000$, $d = 2.92$. In a similar manner, comparison group participants were able to score higher in their posttest (M = 70.4%, SD = 11.4) as opposed to their pretest (M = 33.6%, SD = 12.7), a statistically significant mean increase of 36.8%, 95% CI [28.8, 44.8], $t(22) = 9.537$, $p < .000$, $d = 1.99$. Effect size (Cohen's *d*) calculations show that participation in either of the educational interventions had a large magnitude effect on the students' content knowledge. However, the magnitude of the effect size of the experimental group students was almost one standard deviation higher than that of the comparison group students.

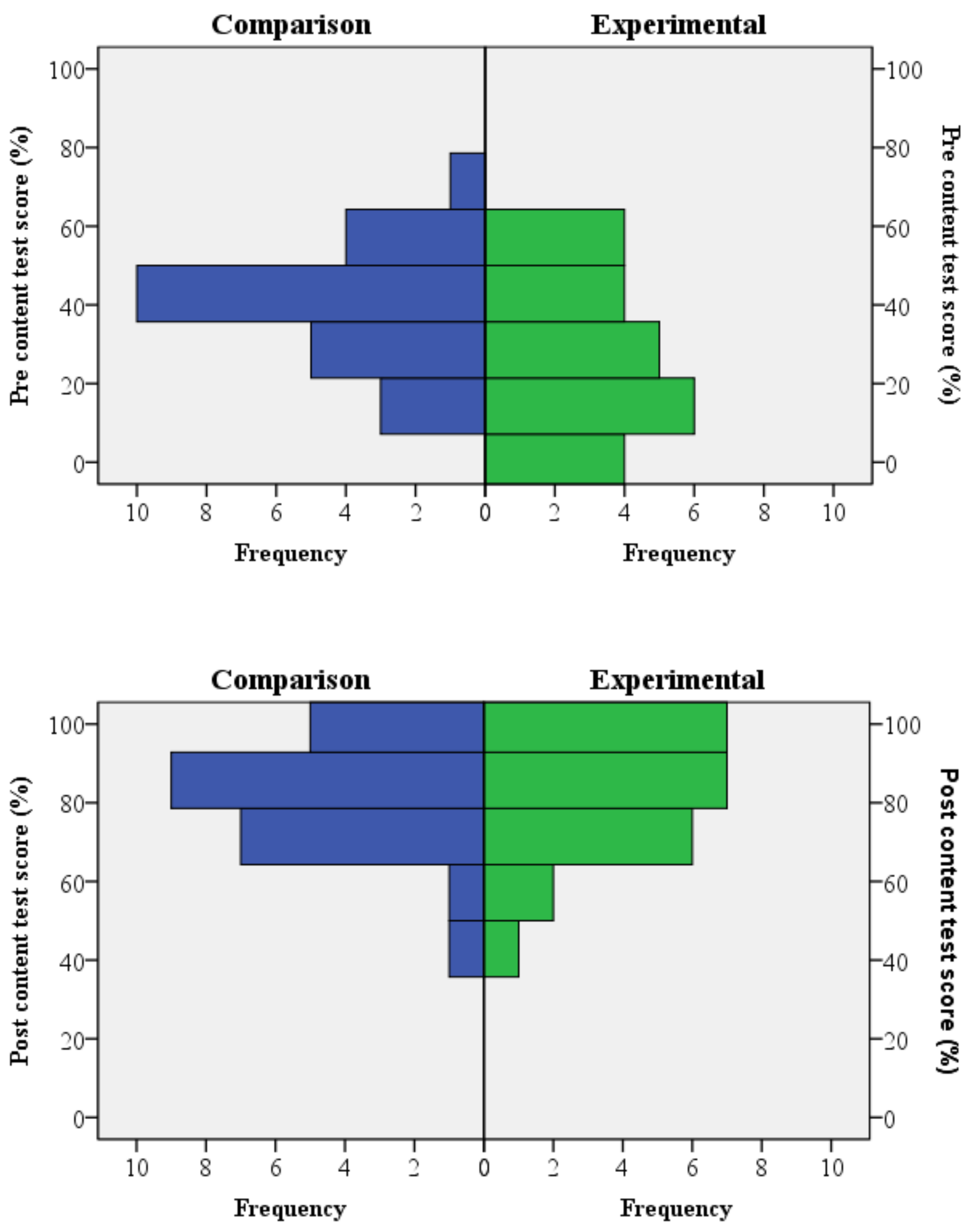
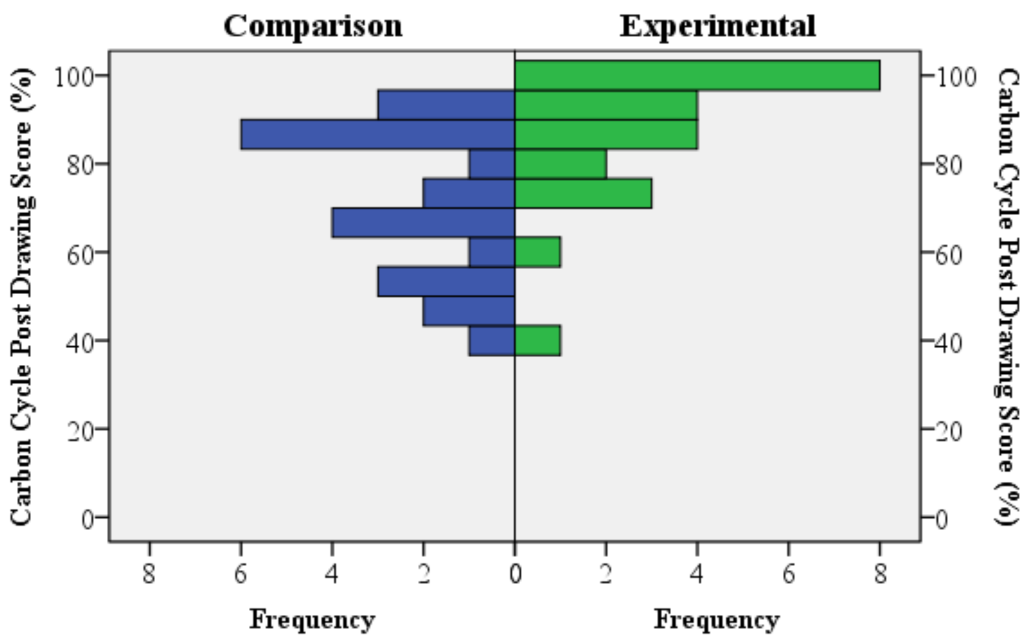


Figure 2. Comparison (n=23) and experimental (n=23) group students' score distributions on the pre (top) and post (bottom) content test.

Independent sample t tests evidenced statistically significant differences between the two groups' content knowledge on the pre administration of the content test, favoring the comparison group students. Therefore, even though both groups were thought to be similar, in terms of their academic achievement, the comparison group students demonstrated significantly higher knowledge of the content assessed on the content test before participating in the educational intervention. For this reason, an ANCOVA was run to determine the effect of the different teaching strategies on post-intervention students' learning gain after controlling for pre-intervention students' content knowledge. After this adjustment, a statistically significant difference was found in the content knowledge of the students from each intervention, $F(1, 43) = 12.091$, $p < .001$, $\eta^2 = .219$. After the educational interventions the experimental group students were able to evidence a statistically significantly higher learning gain than that of the comparison group students. Effect size results show that 21.9% of the variance in the experimental and comparison students' posttest scores can be accounted for by the independent variable of whether or not the student participated in the Project. This outstanding result indicates that participation in the EAL Project had a large magnitude impact on the experimental group students' content knowledge gain, when compared with learning through more traditional style teaching strategies.

Regarding the carbon and the nitrogen drawings, Figure 3 shows the post drawings' score distributions. Illustration of the pre drawings' results was not considered feasible because the great majority of the comparison (91%) and experimental (87%) students scored zero in the pre drawing of the carbon cycle (the maximum score achieved by students from both groups was 7%) while all students from both groups scored zero on their pre drawing of the nitrogen cycle.



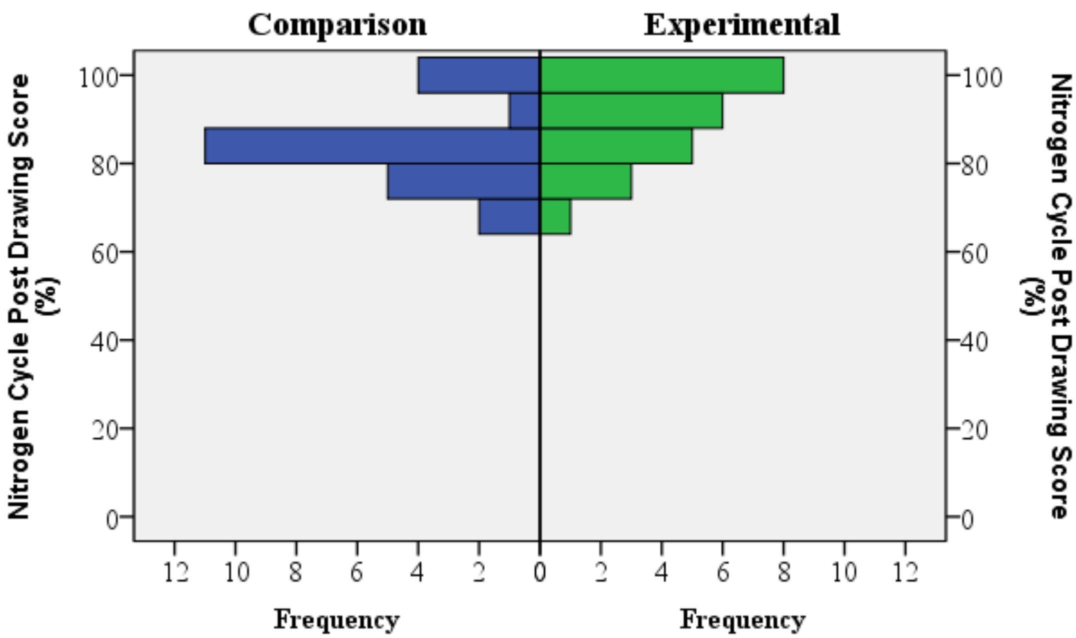


Figure 3. Comparison (n=23) and experimental (n=23) students' score distribution on the post carbon (top) and post nitrogen (bottom) cycles drawings.

Findings from the drawings' rubrics also evidence increases in the students' content knowledge of the carbon and nitrogen cycles after participating in their corresponding educational intervention. Score distributions shown in Figure 3 indicate that all of the perfect scores in the post carbon cycle drawings (n=8) belong to students from the experimental group. Students from both groups obtained perfect scores in their post nitrogen cycle drawings but the number of experimental students doubled that of the comparison students (4 or 17% vs. 8 or 35%). Finally, results show that the students, in general, had less difficulty gaining understanding and mastery of the content knowledge associated with the nitrogen cycle when compared to that of the carbon cycle.

Independent samples t-tests were conducted to determine if there were differences among the experimental and comparison group students' content knowledge of the carbon and nitrogen cycles, as assessed with the rubric of the post drawings. The experimental group students scored higher in their post drawing of the carbon cycle (M = 86.96%, SD = 15.24) than comparison group students (M = 71.30%, SD = 16.99), a statistically significant difference, M = 15.7, 95% CI [6.06, 25.24], $t(44) = 3.289$, $p = .002$, $d = .92$. Also, the experimental group students were able to score higher in their post drawing of the nitrogen cycle (M = 89.91%, SD = 9.71) than comparison group students (M = 84.00%, SD = 9.34), a statistically significant difference, M = 5.91, 95% CI [.25, 11.58], $t(44) = 2.104$, $p = .041$, $d = .62$.

Effect size results show that participation in the EAL Project had a large magnitude impact on the experimental group students' content knowledge gains, as assessed by the drawings. Common Language effect size (Lenhard & Lenhard, 2016) indicates that the chance that, for a randomly selected pair of individuals, the score of a student from the experimental group is higher than the score of a student from the comparison group is 75.4% for the carbon cycle drawing and 67.0% for the nitrogen cycle drawing. In summary, the effect size calculations of all three assessment instruments (content test and drawings of each cycle) indicate that participation in the EAL Project had "substantively important" (Institute of Education Sciences, 2017, p.77) effects on the experimental students' learning gain.

To provide deeper understanding of possible differences in the content learning generated by each teaching strategy, results of the content test and carbon cycle drawing were examined by item. Analysis by item of the nitrogen cycle post drawing is not included because the students' overall mastery of the content made differences between the experimental and comparison group students less evident. Table 1 shows the change (post-pre) in the number of students who answered correctly each item during the pre and post administration of the content test.

Table 1: Change (post-pre) in the amount of experimental (exp., n=23) and comparison (comp., n=23) group students who answered each item of the content test correctly

Item	Change in correct answers (post-pre)		Difference (Exp.-Comp.)
	Exp.	Comp.	
	Frequency (%)		
5. Life on Earth depends on the recycling of water, carbon, nitrogen and phosphorus	9 (39)	10 (43)	-1 (-4)
6. Function of detritivores in the carbon cycle	16 (70)	5 (22)	11 (48)
7. Basis of the carbon cycle.	9 (39)	11 (48)	-2 (-9)
8. Plants and animals must transform nitrogen to use it	15 (65)	11 (48)	4 (17)
9. Principal processes of the nitrogen cycle	17 (74)	14 (61)	3 (13)
10. Part of the carbon cycle directly associated with the Earth's internal heat	7 (30)	6 (26)	1 (4)
11. Part of the carbon cycle directly associated with solar energy	15 (65)	10 (43)	5 (22)

Note: Items 1-4 were excluded from the analysis because they measure knowledge of composting.

Results presented in Table 1 show that a higher difference in the students' learning gain was only observed for item #6. This item #6 states: "What would happen to the carbon cycle if all the detritivores suddenly stopped performing their function?". While from the pre to the post administration of the test the amount of experimental group students who answered it correctly increased by 16, only five more comparison group students demonstrated content knowledge gain by answering this question incorrectly in their pretest and correctly in their post content test. These results seem to suggest that the majority (52%) of the comparison group students knew about the detritivores' role in the carbon cycle before being exposed to the educational intervention. This marks a big contrast with the experimental group students, since just 13% answered it correctly in the pretest while 83% chose the correct answer in the posttest.

Table 2 presents the frequency and percentage of students who achieved the maximum score (5 points) on each criteria of the rubric used to assess the carbon cycles' post drawing.

Table 2: Results of the experimental (exp., n=23) and comparison (comp., n=23) groups' post carbon cycle drawing

Criteria	Students with maximum score		
	Exp.	Comp.	Difference (Exp.-Comp.)
	Frequency (%)		
1. Explains and represents how plants capture CO_2 from the air through the process of photosynthesis and produce sugars…	20 (87)	13 (57)	7 (30)
2. Explains and illustrates how first order heterotrophs obtain organic compounds by feeding on autotrophs.	17 (74)	13 (57)	4 (17)
3. Explains and illustrates how organic compounds can move to higher level heterotrophs.	17 (74)	11 (48)	6 (26)
4. Explains and illustrates how carbon compounds in detritus…and all kinds of dead organisms, are consumed and degraded by detritivores	16 (70)	9 (39)	7 (30)
5. Explains and illustrates how respiration and the decomposition of dead organisms returns carbon to the atmosphere…	15 (65)	10 (43)	5 (22)
6. Uses arrows to indicate the direction of flow of carbon along the carbon cycle processes	14 (61)	6 (26)	8 (35)

Results presented in Table 2 show that more students (differences ranging from 17-35%) from the experimental group were able to achieve the maximum score on all of the criteria used to assess the carbon drawing. This means that more experimental group students were able to accurately illustrate and explain in their post carbon cycle drawing: (a) sources of CO_2, (b) the process of photosynthesis, (c) the process of cellular respiration as a route that returns CO_2 to the atmosphere, and (d) the role of microorganisms in the transformation of dead matter.

Greater differences between the experimental and comparison groups' carbon cycle drawings were identified when the number of students who scored zero in the criteria was examined. None (including the three students with learning disabilities) of the experimental group students scored zero in any of the six criteria of the post carbon cycle drawing. However, five (22%) of the comparison group students scored zero in criteria #4 and seven (30%) in criteria #5. A total of four (17%) comparison group students scored zero in both criteria #4 and #5. Therefore, from 17% to 30% of the comparison group students were unable to explain or illustrate the last stages of respiration and decomposition on their carbon cycle drawing. These students left their carbon cycles incomplete when they omitted the processes necessary to return carbon to the atmosphere.

As previously mentioned, this specific aspect of the carbon cycle was included in the content test with item #6. Examination of the carbon drawing and the content test results by student shows that most of the students who were unable to illustrate the process in the drawing answered item #6 correctly in the content test. These results may suggest a difference in the depth of learning achieved by some of the students exposed to each strategy. While most comparison group students were able to answer item #6 correctly in the pre (52%) and post (74%) administration of the content test, some (17-30%) of these students were unable to explain or illustrate it in their carbon cycle drawings.

Holthuis, Deutscher, Schultz & Jamshidi (2018, p. 25) describe the assessment of PBL as a "significant challenge for teachers". Condliffe et al. (2017, p. 50) note the need to "adopt new modes of assessment that more closely align with PBL's deeper learning goals". We consider that the drawings served this purpose. Results from the rubric used to assess the carbon cycle drawing indicate that the experimental students were able to build deeper learning than the comparison students. Findings obtained suggest that these differences in the depth of understanding could have gone unnoticed had the content test been used as the sole measure to assess student learning gain.

In summary, students from both groups evidenced holding many of the common misconceptions about the carbon and nitrogen cycle before participating in the educational interventions. However, after the educational interventions, all of the experimental group students and most of the comparison group students were able to explain and/or illustrate important aspects of the steps, processes, and key players of the cycles. Also, they were able to evidence the sequence in which each of these aspects are connected to create the cycle. Nonetheless, results show that some comparison group students (17%-30%) were unable to evidence understanding of how organic matter is released back into the atmosphere. This could be an indicator of the prevalence of misconceptions about the decomposition of dead matter even after the students' participation in a traditional teaching educational intervention. Therefore, the results obtained suggest that using common problems and their possible solutions to contextualize the teaching and learning processes could increase the likelihood of addressing and correcting students' common misconceptions regarding the carbon and nitrogen cycles.

In other words, for some students, the more active, prolonged, and context-focused strategy of PBL, might have made the difference in the achievement of learning at higher levels of understanding and comprehensiveness. This may have been the case for the comparison group students who scored zero in some of the criteria of their carbon cycle drawings, and for the three experimental group students with learning disabilities that were able to demonstrate deeper learning of the carbon cycle content. Other studies have associated increases in learning outcomes of students with learning disabilities with PBL's experiential curriculum, focus on cooperative learning, use of authentic contexts for learning, and creation of less restrictive and more inclusive environments (Condliffe et al., 2017).

Finally, informal teacher observations of the students' interest in the class activities indicate that the experimental group students were highly motivated by the EAL Project. The students' increased interest in learning science was evident in their: (a) enthusiasm for the weekly science period dedicated to data collection at the compost and crop station; (b) active participation in discussions generated by their observations of how the compost formed and affected plant growth; (c) willingness to work cooperatively, particularly with the integration of the three students with learning disabilities to the rest of the group; (d) willingness to dedicate outside class time to the Project by scheduling when and who would water the plants, and by working (and inviting their parents) on weekends; and (e) application of their learning outside the school setting (in some cases) by preparing compost for their home gardens. The observed effects of PBL on students' interest towards school science are in alignment with Huggerat's (2016) study which "revealed students who learned science by project-based learning teaching strategies perceived their classroom learning climate as significantly more Satisfying and Enjoyable, with greater Teacher Supportiveness and the Teacher-Student Relationship as significantly more positive" (p. 383).

Conclusion

Results obtained from this action research indicate that directly and repeatedly addressing common misconceptions has a positive effect on students' content learning of the carbon and nitrogen cycles. However, students who participated in the PBL strategy showed statistically significantly higher content learning gains than their comparison group peers in the three different measures used to assess content knowledge. Thus, results suggest that students from the comparison group may have gained deeper and more comprehensive knowledge of the cycles if their learning had been through PBL instead of the traditional teaching strategies. Finally, the teacher perceived that the contextualization of the content on a relevant problem and its possible solutions increased her students' interest towards school science learning. Thus, the results of this action research support the use and effectiveness of PBL in promoting meaningful learning, which includes both the conceptual and attitudinal aspects of learning, understanding, and applying science to life.

The mission of the PRDE Science Program is to contribute to the formation of scientifically and technologically literate individuals that will be productive members of the present and future global society (PRDE, 2014). In accordance with this mission, problem and project- based learning have been established as the main strategies for classroom teaching and learning processes (PRDE, 2014). We hope that our experience with the EAL Project may serve as an example and inspiration for other teachers that may be struggling with the implementation of

PBL, or with their students' learning barriers due to misconceptions or lack of interest towards learning science.

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Appendix A: Pretest and Posttest – Carbon and nitrogen cycles

Instructions: Read each question carefully and select the option that corresponds to the best answer. (Correct answers are marked with an asterisk *)

_____1. The main process that occurs during the formation of "compost" is:

a. decomposition *
b. compaction
c. photosynthesis
d. evaporation

_____ 2. All of the following compost factors are considered abiotic EXCEPT:

a. the addition of moisture for organisms that need oxygen.
b. the aeration that provides oxygen to organism that need it to live.
c. the earthworm's contribution in the decomposition of organic solid waste.*
d. the surface area that compost components must have in order to speed up decomposition.

_____ 3. Identify the factors that may affect the compost formation process:

a. Rain, pressure, heat, microorganisms, moisture, oxygen
b. Humidity, temperature, oxygen, pH, nitrogen/carbon content*
c. Heat, water, micro and macro organisms, nitrogen/carbon content
d. Temperature, surface area, pressure, humidity, pH

_____ 4. Organic wastes that are green provide a high content of ___________ to the compost; on the other hand, the brown colored ones provide more ____________.

a. carbon; nitrogen
b. nitrogen; carbon*
c. phosphorus; potassium
d. potassium; phosphorus

_____ 5. While the sun provides energy to ecosystems, no external sources provide water, carbon, nitrogen and phosphorus to our planet. Therefore, life on earth depends on:

a. increasing the production of these chemicals.
b. alternating the use of these chemicals.
c. avoiding the use of these chemicals.
d. the natural recycling of these chemicals.*

_____ 6. What would happen to the carbon cycle if all the detritivores suddenly stopped performing their function?

a. Carbon would accumulate as organic mass, which would decrease its atmospheric reserve and plants would die from lack of CO_2.*

b. Carbon would accumulate as organic mass, which would increase its atmospheric reserve and plants would grow with the CO_2 increment.
c. Carbon would be released as organic mass, which would decrease its atmospheric reserve and plants would die from a lack of CO_2.
d. There would be no change in the carbon cycle, the atmospheric carbon reserves would remain stable and plants would grow normally.

_____ 7. The main process of the carbon cycle is:

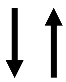
a. Combustion
b. Respiration
c. Photosynthesis*
d. Decomposition

_____ 8. Nitrogen (N_2) constitutes approximately 78% of the terrestrial atmosphere. In spite of this, nitrogen:

a. is not used by plants and animals.
b. is used by animals, but not by plants.
c. has to be transformed in order to be used by plants and animals.*
d. has to be decomposed by animals so that plants can use it.

_____ 9. The nitrogen cycle includes four core processes:

a. nitrogen fixation, ammonification, denitrification and respiration.
b. nitrogen fixation, ammonification, nitrification and denitrification. *
c. nitrogen fixation, combustion, nitrification and denitrification.
d. nitrogen fixation, ammonification, respiration and combustion.



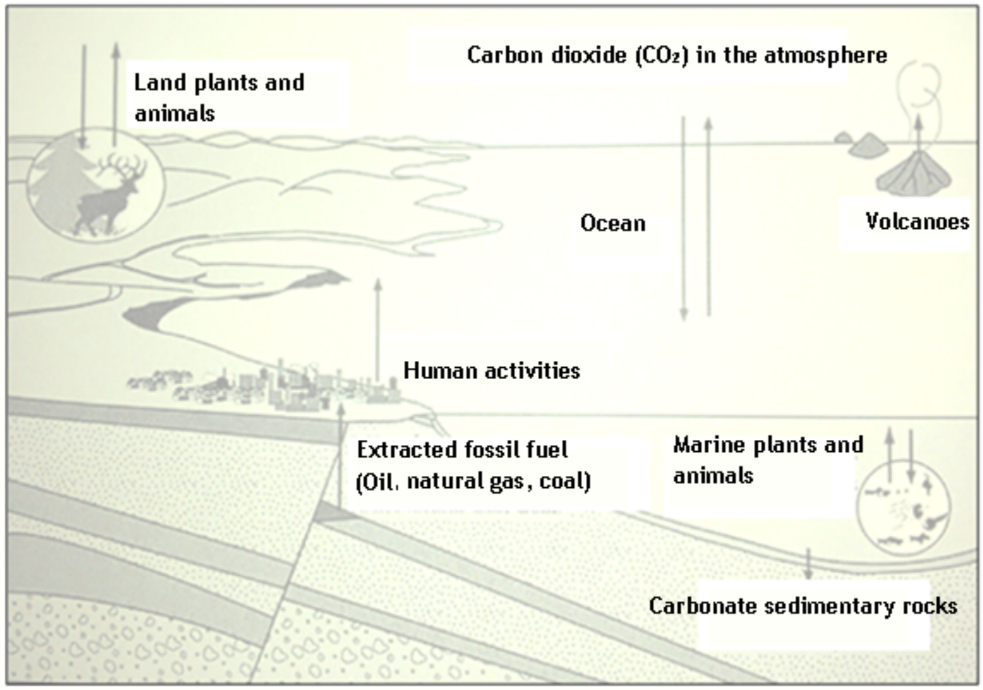


Figure 1
SOURCE: U.S. Department of Education, Institute of Education Sciences, National Center for Education Statistics, National Assessment of Educational Progress (NAEP), 2013. Reading Assessment.
http://nces.ed.gov/NationsReportCard/nqt/Search

The direction of the arrows indicates the direction in which carbon flows through the carbon cycle. The length of the arrows indicate the relative amount of carbon transferred.
Use Figure 1 to answer questions 10 and 11 (Correct answers are marked with an asterisk *)

_____ 10. What portion of the carbon cycle is directly driven by the Earth's internal heat energy?

a. The movement of carbon between the ocean and the atmosphere.
b. The emission of carbon dioxide from factories that burn oil.
c. The release of carbon dioxide during volcanic eruptions.*
d. The carbon dioxide exhaled by animals

_____ 11. What portion of the carbon cycle is directly driven by the sun's energy?

a. The formation of coal under layers of rocks.
b. The release of carbon dioxide during volcanic eruptions.
c. The emission of carbon dioxide from factories that burn fuel.
d. The formation of sugar on the Earth's surface.

Appendix B: Rubric to evaluate the carbon cycle drawing

CARBON CYCLE			
Evaluation Criteria			
5 points	3 points	1 point	0 points
1. Explains and represents how plants (autotrophic) capture CO_2 from the air through the process of photosynthesis and produce sugars and other organic compounds formed from sugars.	Explains how the plants (autotrophic) capture CO_2 from the air through the process of photosynthesis and produce sugars and other organic compounds formed from sugars.	Represents how the plants (autotrophic) capture CO_2 from the air through the process of photosynthesis and produce sugars and other organic compounds formed from sugars.	Does not explain nor represent how the plants (autotrophic) capture CO_2 from the air through the process of photosynthesis and produce sugars and other organic compounds formed from sugars.
2. Explains and illustrates how first order heterotrophs obtain organic compounds by feeding on autotrophs.	Explains how first order heterotrophs obtain organic compounds by feeding on autotrophs	Illustrates how first order heterotrophs obtain organic compounds by feeding on autotrophs.	Does not explain nor illustrate how first order heterotrophs obtain organic compounds by feeding on autotrophs.
3. Explains and illustrates how organic compounds can move to higher level heterotrophs.	Explains how organic compounds can move to higher level heterotrophs.	Illustrates how organic compounds can move to higher level heterotrophs.	Does not explain nor illustrate how organic compounds can move to higher level heterotrophs.
4. Explains and illustrates how carbon compounds in detritus, animal waste, fallen leaves, and all kinds of dead organisms, are consumed and degraded by detritivores (fungi, bacteria, etc.).	Explains how carbon compounds in detritus, animal waste, fallen leaves, and all kinds of dead organisms, are consumed and degraded by detritivores (fungi, bacteria, etc.).	Illustrates how carbon compounds in detritus, animal waste, fallen leaves, and all kinds of dead organisms, are consumed and degraded by detritivores (fungi, bacteria, etc.).	Does not explain nor illustrate how carbon compounds in detritus, animal waste, fallen leaves, and all kinds of dead organisms, are consumed and degraded by detritivores (fungi, bacteria, etc.).
5. Explains and illustrates how respiration and the decomposition of dead organisms returns carbon to the atmosphere and completes the cycle.	Explains how respiration and the decomposition of dead organisms returns carbon to the atmosphere and completes the cycle.	Illustrates how respiration and the decomposition of dead organisms returns carbon to the atmosphere and completes the cycle.	Does not explain nor illustrate how respiration and the decomposition of dead organisms returns carbon to the atmosphere and completes the cycle.

Appendix C: Rubric to evaluate the carbon cycle drawing

CARBON CYCLE			
Evaluation Criteria			
5 points	3 points	1 point	0 points
6. Uses arrows to indicate the direction of the flow of carbon along the following processes : Plants (autotrophic) capture CO_2 from the atmosphere and produce sugars. First order heterotrophs obtain organic compounds, which are passed on to higher-level heterotrophs. Carbon compounds in detritus, animal waste, fallen leaves, and dead organisms of all kinds are consumed and degraded by detritivores. The cycle is completed when carbon is returned to the atmosphere through respiration and the decomposition of dead organisms.	Uses arrows to indicate the direction of the flow of carbon, on at least three of the following processes: Plants (autotrophic) capture CO_2 from the atmosphere and produce sugars. First order heterotrophs obtain organic compounds, which are passed on to higher-level heterotrophs Carbon compounds in detritus, animal waste, fallen leaves, and dead organisms of all kinds are consumed and degraded by detritivores. The cycle is completed when carbon is returned to the atmosphere through respiration and the decomposition of dead organisms.	Uses arrows to indicate the direction of the flow of carbon, on at least two of the following processes: Plants (autotrophic) capture CO_2 from the atmosphere and produce sugars. First order heterotrophs obtain organic compounds, which are passed on to higher-level heterotrophs. Carbon compounds in detritus, animal waste, fallen leaves, and dead organisms of all kinds are consumed and degraded by detritivores. The cycle is completed when carbon is returned to the atmosphere through respiration and the decomposition of dead organisms.	Does not use arrows to indicate the direction of the flow of carbon on the various stages of its cycle.
Total:			

Appendix D: Rubric to evaluate the nitrogen cycle drawing

NITROGEN CYCLE			
Evaluation Criteria			
5 points	3 points	1 point	0 points
1. Explains or represents the nitrogen (N_2) sources or in the wild: a. air b. thunderstorms c. dead plants or plant debris d. dead animals or waste of these	Explains or represents at least two nitrogen sources in the wild.	Explains or represents one of the nitrogen sources in the wild.	Does not explain or represent nitrogen sources in the wild.
2. Explains the four major processes that occur during the cycle: a. nitrogen fixation b. ammonification c. nitrification d. denitrification	Explains at least two of the four core processes that occur during the cycle.	Explains one of the four core processes that occur during the cycle.	Does not include the core processes that occur during the cycle.
3 Explains the transformations that nitrogen undergoes, in order to be used by plants and animals, and for returning back into the atmosphere: a. nitrogen (N_2) b. ammonia (NH_3) c. nitrate (NO_3) d. nitrite (NO_2)	Explains at least two of the transformations that nitrogen undergoes, in order to be used by plants and animals, and for returning back into the atmosphere:	Explains at least one of the transformations that nitrogen undergoes, in order to be used by plants and animals, and for returning back into the atmosphere.	Does not explain the trans-formations that nitrogen undergoes, in order to be used by plants and animals, and for returning back into the atmosphere.

Appendix E: Rubric to evaluate the nitrogen cycle drawing

NITROGEN CYCLE			
Evaluation Criteria			
5 points	3 points	1 point	0 points
4. Identifies the organisms that intervene in the various transformations of N_2 and its importance in the cycle. a. nitrogen-fixing bacteria b. bacteria that degrade animal waste or carcasses of dead organisms c. bacteria that convert ammonia into nitrites and nitrites into nitrates d. anaerobic bacteria that convert nitrate into nitrogen	Identifies at least two of the organisms that intervene in the various transformations of N_2, and its importance in the cycle.	Identifies one of the organism that intervene in the various transformations of N2, but not its importance in the cycle.	Does not identify the organisms that intervene in the various transformations of N_2, neither its significance in the cycle.
5. Uses arrows to indicate the direction in which all cycle processes occur: movement of different nitrogen sources movement of the core processes movement of the transformations by which nitrogen undergoes	Uses arrows to indicate the direction in which at least two of the cycle processes occur: movement of the different nitrogen sources movement of the core processes movement of the transformations by which nitrogen undergoes	Uses arrows to indicate the direction in which at least one of the cycle processes occur: movement of the different nitrogen sources movement of the core processes movement of the transformations by which nitrogen undergoes	Does not use arrows to indicate the direction in which the cycle occurs.
Total:			